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Evaluating The Impact Of Forest Management On Water Quality

by

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We know that some forest management practices, under certain conditions, increase sediment loads in streams. Research at Coweeta Hydrologic Laboratory and Fernow Experimental Forest, for example, has demonstrated that poorly built skid trails and logging roads increase sediment yields of watersheds; and Ursic (5) found that prescribed burning upland hardwoods in northern Mississippi increased sediment production. However, research has not evaluated all the common forestry practices for sediment production. Nor do we know how much sediment these practices produce under a management situation when they are scattered over a large watershed or river basin. What is the impact of each practice on the water quality for various uses downstream? How can the watershed planner evaluate his land management recommendations in terms of impact to water quality?

In the Southeastern Area, a procedure has been developed to help answer these questions and has been used successfully in river basin planning. It's called First Approximation of Suspended Sediment. FASS provides river basin and watershed planners, as well as land managers, with a tool to measure the impact of present management on suspended sediment, identify problems, and evaluate alternative solutions to reduce suspended sediment.

Briefly, FASS incorporates the Musgrave equation (4) to compute sheet erosion, then goes further to determine gully erosion. Next, it estimates what proportion

of the total erosion-sheet plus gully-becomes sediment in the streams and reservoirs, and how much is caused by each land disturbance. With such quantitative information, the forest manager can alter his practices to bring about a sedimentation level that meets water quality standards. He can also use the information on another watershed of similar characteristics to evaluate proposed practices.

First, we stratify the study area using those characteristics that affect erosion and sediment yields such as soils, slope, vegetation types, land ownership, land use, and unusual disturbances. For the most part, this can be done through the use of available maps and data. However, in the case of unusual disturbances such as fires and strip mining, information must be gathered on the ground. The acreage of each strata is totalled, and those occupying more than one percent of the study area or having unusual disturbances are field sampled to develop erosion rates. The modified Musgrave equation(4) is used to compute sheet erosion for each plot:

$$E = KCR\left(\frac{S}{10}\right)^{1.35}\left(\frac{L}{72.6}\right)^{0.35}$$

E = Sheet erosion, tons per acre per year
SCS K = Erosion rate of soil series, in tons per acre per year per unit of rainfall index
C = Cover factor
R = Rainfall factor
S = Land slope in percent
L = Length of slope in feet

Only a proportion of the sheet erosion, of course, reached the nearest stream. Therefore, we trace the soil movement downhill and estimate what proportion is not trapped by obstructions. The sheet erosion is multiplied by this proportion to approximate a sediment production rate in tons per acre per year.

The next step is to measure the amount of gully erosion(G) that occurred during an evaluation period and to convert this to tons per acre per year. Again, sediment production from the gully erosion is estimated. The sheet and gully erosion are added together producing a total erosion rate for the plot. Likewise, a total sediment production rate is determined for each plot.

The total erosion rates (E+G) of the individual plots are plotted as a function of the Musgrave K-factor and slope classes by causes of erosion (Figure 1). Such a plotting is made for each cause of erosion, such as natural, logging, fire, skid trails, and logging and burning.

These plottings are used to project an erosion rate for each stratum. For example, let's assume that a stratum has an average K-factor of 0.32, average slope of 10 percent and is undisturbed. In Figure 1, the natural erosion rate for this stratum is determined by projecting the 0.32 K-factor up to the 10 percent slope line for natural erosion and across, producing 0.037 tons per acre per year. If another stratum had the same K-factor and average slope, yet was logged, a similar projection would be made by using the logged curve, producing 0.460 tons per acre per year. The logged stratum is experiencing two quantities of erosion: natural plus the accelerated erosion due to logging. Therefore, the accelerated erosion due to logging equals the 0.460 minus 0.037 or 0.423 tons per acre per year. By the same procedure, we can determine the accelerated erosion due to logging and burning over that of logging alone, or any other combination of causes.

An average sediment delivery ratio is computed for each stratum using the plot data. It is computed by dividing the average sediment production rate by the average erosion rate for the plots by stratum. This ratio is then multiplied

by the projected erosion rate to produce the sediment production rate for each stratum.

The volume of erosion produced by each disturbance within the basin is calculated simply by multiplying the erosion rate by the strata area for each disturbance. The volume of sediment production by disturbance is computed in like manner. The total volume of erosion and sediment production is merely the sum of these volumes by disturbances.

We now have the estimated volume of forest erosion and sediment production in the basin. The Soil Conservation Service evaluates erosion and sediment production from the nonforested areas, such as agricultural lands, highways, urban areas, and channel erosion. The volume of forest erosion is added to the volumes computed by the SCS to produce the gross erosion for the basin. Then the percent of the gross erosion produced by forest land is computed.

What we mainly have accomplished so far is to determine proportions of erosion and sedimentation that can be attributed to each forest disturbance. The fact that volumes have been only estimates is of little consequence; in the second part of the procedure we will determine the volumes more accurately.

From this point, we proceed in one of two directions, depending on what downstream sediment yield data is available. The first and preferred alternative is to use suspended sediment data if it is available. Table I contains a representative example, with the causes of erosion on forest land listed in the left hand column and the corresponding area of each disturbance in the next column. Forests occupy 6.5 out of 10.3 million acres or 63 percent of the area.

The computed erosion by cause is presented in the next column with forest
2 land producing 4,454,300 tons per year---10 percent of the gross erosion for
the basin. This forest proportion is used later to allocate sediment yield to
forest practices.

3 The next column contains the estimate of how much erosion by cause reaches
the nearest stream channel. These volumes are added to produce a total estimated
sediment production. The volume by cause is divided by the total to produce
4 the proportion of estimated sediment production by cause listed in the next
column. Thus, these proportions identify the relative importance of each
disturbance as a sediment producer and a water polluter within the forest.

In this basin, the average annual suspended sediment concentration is 340 mg/1.
5 It is assumed that the proportion of suspended sediment contributed by the
forest and forestry activities approximately equals the ratio of forest erosion
to basin erosion. Therefore, the forest is allotted 10 percent or 34 mg/1.
This is multiplied by the various proportions of estimated sediment production
6 to compute the average annual suspended sediment contribution by each cause of
erosion found in Column 6.

Let us assume this basin has reservoirs that trap slugs of muddy stormflow. This adversely affects recreation and fishery because the suspended sediment requires an extended period of time to settle; therefore, the impact of forestry activities on water quality of stormflows should be evaluated. For this basin, stormflow volume equals approximately 44 percent of average annual flow. Research has generally demonstrated that approximately 90 percent of sediment yield occurs during stormflow periods (1,2). The average suspended sediment concentra-

tion for stormflow is computed with the following formula:

$$WQ_s = \frac{0.90\ WQ_m}{S} = \frac{0.90\ (340\ mg/1)}{0.44} = 695$$

Where:

WQ_s = Average suspended sediment concentration (mg/1) in stormflow

WQ_m = Average annual suspended sediment concentration (mg/1)

S = Proportion of annual runoff contributed by stormflow

7

Therefore, the average stormflow concentration is 695 mg/1 of suspended sediment, of which forest is allotted 10 percent or 69.5 mg/1. This volume is distributed among the causes of erosion, following the same procedure used to compute the average annual suspended sediment, and is presented in column 7.

The forest manager should also be concerned about the baseflow water quality because fish, although they can stand short periods of high sediment concentrations, need high quality water on a continuing basis for good reproduction and habitat. If 90 percent of the sediment is yielded during stormflow periods, then baseflow must yield 10 percent. For this example, 56 percent of the annual flow is baseflow. The average suspended concentration during baseflow is:

$$WQ_b = \frac{0.10\ WQ_m}{B} = \frac{0.10\ (340\ mg/1)}{.56} = 61\ mg/1$$

Where:

WQ_b = Average suspended sediment concentration (mg/1) in baseflow

WQ_m = Average annual suspended sediment concentration (mg/1)

B = Proportion of annual runoff contributed by baseflow

Consequently, the average baseflow concentration is 61 mg/l with 6.1 mg/l assigned to forest land. In Column 8, this allotment is again distributed among the causes of erosion. Thus ends the procedure when suspended sediment data is available.

Water quality impacts also can be evaluated from reservoir sedimentation data. This procedure is presented in Table 2. The reservoirs in this basin trap 6,174,000 tons per year of sediment, and again the forest is allotted 10 percent or 617,400 tons per year. The portion is allocated to the causes of erosion, using the same proportions of estimated sediment production as in Table 1, Column 5. Column 4 in Table 2 contains the average sediment yield rate which is the quotient of sediment yield divided by area of each disturbance.

The sediment trapped in reservoirs is delivered either as bedload or suspended sediment. The proportion that is delivered as suspended sediment can be approximated by using soils data and knowledge of the stream. For this example, the river is relatively slow moving where only silts and clays are probably carried in suspension. Based on soils data, the weighted average proportion of fines in the basin soils is 55 percent. Because logging, fire, skid trails, spur roads and landings occur throughout the basin, their sediment yield rates are multiplied by 0.55 to approximate the rate at which fines are contributed by each disturbance (Column 6). Mechanical site preparation was confined to a belt of clay loam soils which average 65 percent fines.

This procedure is based upon a unit area concept and converting the average yield of fines to suspended sediment concentrations. Therefore, in Column 7, the area of each disturbance is expressed as a proportion of unity or a representative acre.

Conversion factors are developed for a ton of suspended sediment to milligrams per liter of annual, base and storm flows. For this basin, annual, base and storm flows equal 17.0, 9.5, and 7.5 inches, respectively. The conversion factors for these flows are as follows:

Stormflow	1,177 mg/1/ton
Baseflow	929
Annual Flow	520

Finally, three simple formulas are used to compute average sediment concentrations by disturbance for the three types of flow:

SSa = Ka(S) (A) where:

SSa = Average annual suspended sediment concentration - mg/1

S = Average annual yield of material assumed to be carried in suspension in tons per acre per year

A = Proportion of representative acre occupied by the disturbance

Ka = Conversion factor for average annual flow - mg/1/ton

SSb = 0.1 (Kb) (S) (A) where:

SSb = Average suspended sediment concentration for baseflow -mg/1.

Kb = Conversion factor for baseflow - mg/1/ton

SSs = 0.9 (Ks) (S) (A) where:

SSs = Average suspended sediment concentration for stormflow - mg/1

Ks = Conversion factor for stormflow - mg/1/ton.

In Table 2, the suspended sediment concentrations presented for annual, storm and base flows in columns 8, 9 and 10, respectively, are slightly lower than corresponding values in Table 1, but both procedures provide approximately the same answers for this example.

It should be emphasized that these suspended sediment contributions are in addition to what natural channel erosion may be contributing. Lull and Reinhart (3) report research on sediment yield from forested watersheds in the east where nonstorm periods had turbidities of 2 to 5 ppm and stormflow generally under 10 ppm. Their opinion is that these turbidities are the result of stream channel erosion. At these low concentrations, parts per million is essentially equal to milligrams per liter. Therefore, 2 to 5 mg/1 should be added to base-flow, 10 mg/1 to stormflow, and approximately 8 mg/1 to annual concentrations to complete the picture for forest lands. These channel erosion contributions to supsended sediment are entered in Tables 1 and 2 in parentheses and added to the others.

The question now arises, is the forest yielding water that meets water quality criteria for uses downstream? Suppose the water is used for recreation and fishing, and has maximum and optimum criteria of 50 and 5 mg/1, respectively. The 50 mg/1 could be set as a goal for stormflow with the 5 mg/1 as standard for baseflow. As said before, fish can tolerate short periods of high concentrations, but need high quality water most of the year for optimum reproduction.

Either Tables 1 or 2 could be used for this evaluation, but for the purposes of this discussion let's use Table 2, because it shows the importance of disturbed area in sediment production more clearly. The data indicate that the forest is not yielding water that meets these criteria.

What land management activities are causing the problem? Mechanical site preparation is the biggest contributor followed by channel, fire and skid trail erosion. Obviously, not much can be done to reduce channel erosion, but the others can be alleviated.

Three basic actions can be taken to reduce the suspended sediment contributions: (1) install filter strips between disturbance and streams, (2) reduce on-site erosion rates, and (3) reduce the area of disturbance. Sometime during field sampling, filter strips should be evaluated for trap efficiency. On-site erosion rates can be reduced by limiting the percent bare ground, slope, and slope lengths allowed for various management activities. The Musgrave equation can be used to evaluate this reduction. The reduced erosion should produce at least a proportional reduction in suspended sediment. These projected data are run through FASS to predict what the water quality would be under recommended management and compare the results with water quality criteria.

If the first two approaches are not enough to meet water quality criteria, then the area of disturbances must be reduced. Suspended sediment reductions should be proportionated to the area reduction for each disturbance.

Conclusions

FASS provides the land manager with a technique for evaluating his land management with respect to water quality insofar as it is affected by suspended sediment. It provides a means of identifying the causes of water quality problems and identifying what land management changes are needed to meet water quality standards.

Literature Cited

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Table 1 - Water Quality Impact Evaluation Using Suspended Sediment Data

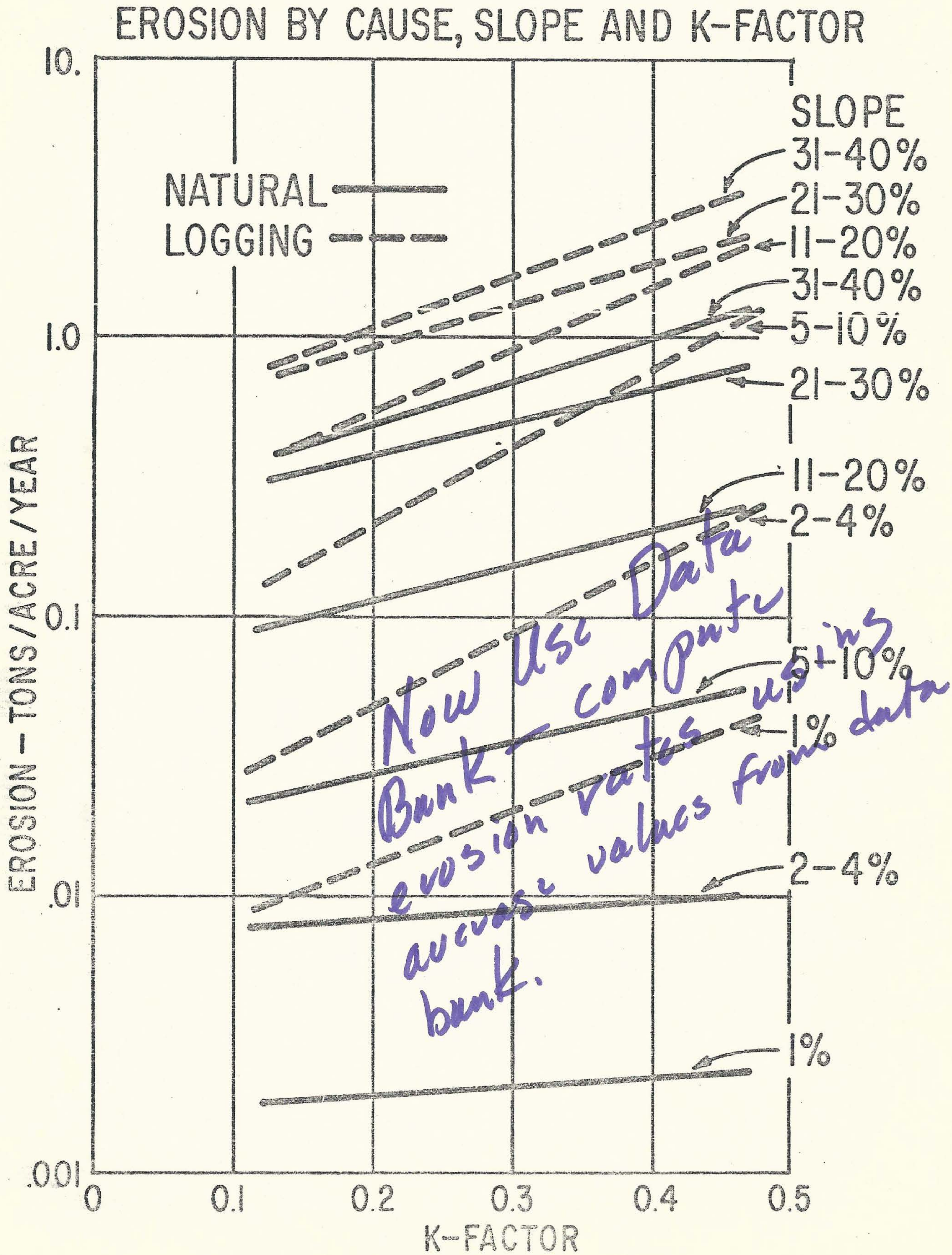
(1) Cause of Erosion	(2) Area Acres	(3) Erosion Tons/year	(4) Est. Sediment Production Tons/year	(5) Proportion of Est. Sediment Production	(6) Average Suspended Sediment MG/L	(7) Average Suspended Sediment in Storm Flow Period MG/L	(8) Average Suspended Sediment in Base-flow period MG/L
Natural	6,500,000	499,100	0	0	(8) 1/	(10) 1/	(3)
Logging	294,000	525,900	7,500	0.006	0.2	0.4	T
Fire	48,300	395,600	126,500	0.099	3.4	6.9	0.6
Skid Trails	5,400	347,400	85,900	0.067	2.3	4.7	0.4
Spur Roads	1,100	69,700	23,600	0.019	0.6	1.3	0.1
Landings	1,700	11,000	800	0.001	T	0.1	T
Mechanical Site Preparation	30,400	2,605,600	1,030,100	0.808	27.5	56.1	5.0
Subtotal-Forest Land	6,500,000	4,454,300	1,274,400	1.000	34.0	69.5	6.1
Forestland and Channel Erosion					(42.0)	(79.5)	(9.1)
Basin Totals	10,300,000	45,312,600			340.0	695.0	60.7
Forest Proportion	0.63	0.10			0.10	0.10	0.10

1/ Suspended sediment from stream channel erosion. (Lull and Reinhart, 1972)

Table 2 - Water Quality Impact Evaluation Using Reservoir Sedimentation Data

(1) Cause	(2) Area Acres	(3) Sediment Yield Tons/Yr.	(4) Average Sediment Yield Rate Tons/Ac/Yr.	(5) Proportion of Fines in Soils	(6) Average Yield of Fines Tons/Ac/Yr.	(7) Proportion of Forest Area	(8) Average Suspended Sediment MG/L	(9) Stormflow Suspended Sediment MG/L	(10) Baseflow Suspended Sediment MG/L
Natural	6,500,000	0	0		0		(8) 1/	(10)	(3)
Logging	294,000	3,700	0.013	.55	0.007	0.0452	0.2	0.3	T
Fire	48,300	61,100	1.265	.55	0.696	0.0074	2.7	5.4	0.5
Skid Trails	5,400	41,400	7.667	.55	4.217	0.0008	1.5	3.5	0.3
Spur Roads	1,100	11,700	10.636	.55	5.850	0.0002	0.6	1.2	0.1
Landings	1,700	600	0.353	.55	0.194	0.0003	T	0.1	T
Mechanical Site Preparation	30,400	498,900	16.411	.65	10.667	0.0047	26.0	53.1	4.7
Subtotal Forest Land	6,500,000	617,400	0.095		0.060	1.0000	31.2	63.6	5.6
Forestland and Channel Erosion							(39.2)	(73.6)	(8.6)
Basin Totals	10,300,000	6,174,000							
Forest Proportion	0.63	0.10							

1/ Suspended sediment from stream channel erosion. (Lull and Reinhart, 1972)



EROSION BY CAUSE, SLOPE AND K-FACTOR
10.
1.0
0.1
.01
.001
0
0.1
0.2
0.3
0.4
0.5
K-FACTOR
EROSION - TONS/ACRE/YEAR
NATURAL
LOGGING
SLOPE
31-40%
21-30%
11-20%
31-40%
5-10%
21-30%
11-20%
2-4%
5-10%
1%
2-4%
1%
Now Use Data Bank – compute erosion rates using average values from data bank.